MULTI-ELEMENT METAL CONTINUOUS EMISSIONS MONITOR FOR COMPLIANCE MONITORING

TECHNOLOGY DESCRIPTION

This project involves the development of a high-resolution, solid-state, compact spectrometer for monitoring spectral emission from an air, inductively coupled plasma, atomic emission spectrometer (air-ICP-AES) system. This fieldable spectrometer provides the resolution and sensitivity of a 1.0- to 1.5-m spectrometer in a package that is less than one-tenth the usual size and weight. The system consists of a 0.38-m echelle-grating spectrometer with an acousto-optic tunable filter (AOTF) performing grating-order selection. An array detector, either a linear photodiode array or a rectangular charged coupled device (CCD) array, detects the dispersed emission. The AOTF is a quartz crystal device that selects a narrow band (~1 nm) of emitted light and rotates its polarization by 90 degrees. When placed between crossed polarizers, only the selected wavelength band is transmitted to the echelle grating. The AOTF wavelength is tuned by changing an applied radio frequency. The AOTF allows extremely rapid sequential or simultaneous selection of wavelengths with no moving parts. The wavelength-switching rate is limited to several milliseconds by the electronics and the speed of the acoustic wave in the quartz crystal.

Compared to more conventional echelle-grating spectrometers that use cross-dispersion gratings or prisms, this spectrometer provides advantages in reduced size, simplified optical components, reduced off-axis aberrations and light losses, minimized exposure of optical components to excessive ultraviolet (UV) source radiation, and smaller and less expensive detector requirements. Compared to tunable-grating spectrometers with comparable resolution, this detection system is smaller, lighter, provides more rapid wavelength tuning, and is more flexible than direct-reader spectrometers that require moving the detector components to change selected lines.

TECHNOLOGY NEED

Draft U.S. Environmental Protection Agency (EPA) regulations for hazardous waste combustion include provisions for the use of continuous emission monitors (CEMs) for six toxic metals in stack gas emissions: arsenic (As), beryllium (Be), cadmium (Cd), chromium (Cr), mercury (Hg), and lead (Pb). The use of CEM technologies is being encouraged to secure the increased assurance of compliance afforded by continuous monitoring systems.

Currently, there are no commercial CEM technologies capable of meeting all of the detection limit requirements and data quality objectives of the proposed rule. The U.S. Department of Energy (DOE) has a number of incinerator sites that will be subject to the proposed regulation when it comes into effect and, therefore, DOE has an interest in developing a CEM capable of meeting the EPA requirements. DOE incinerators that treat mixed waste have the additional need to monitor emissions of alpha-emitting materials, including the isotopes of actinide elements such as uranium (U) and plutonium (Pu). The DOE incinerator sites at which this technology could potentially be deployed include the Toxic Substance Control Act (TSCA) incinerator at Oak Ridge National Laboratory (ORNL), the Waste Experimental Reduction Facility (WERF) incinerator at Idaho National Engineering and Environmental Laboratory (INEEL), and the Consolidated Incineration Facility (CIF) incinerator at the Savannah River Site (SRS).

The conventional technology for monitoring elemental contaminants in stack gases is EPA Method 29. That method is not a continuous monitoring technique at all, but is a protocol for sampling toxic metals from a gas stream for laboratory analysis. Method 29 is used during test burns to verify compliance for a specific range of combustion conditions and feed stream conditions. The EPA method is not continuous, involves long laboratory turnaround times, is fairly labor intensive (each sample requires careful collection and handling and a chain-of-custody paper trail), requires skilled laboratory staff for analyses, and provides little assurance to stakeholders that catastrophic releases do not occur. In addition, the costs for trial burns and the necessary analyses of the waste feed stream are high. Implementation of a CEM, such as the air-ICP-AES, will minimize and ultimately eliminate the need for extensive trial burns and feed stream characterization. CEMs will also give continuous, rapidly updated information on furnace operation, providing operator feedback and assuring regulatory compliance. Routine operation of a CEM may be automated, but a trained technician will be needed to perform periodic maintenance tasks.

The needs identified by Site Technology Coordination Groups (STCG) addressed by this project are as follows:

- OR WM-13 - Metals Monitoring of Gaseous Emissions (Project Baseline Summary (PBS) No. OR-38111)
- SR00-1004 - Need for Continuous Emissions Monitors for Measurement of Hazardous Compound Concentrations in Incinerator Stack Gas (PBS No. SWR-SW01)
- ID-3.2.32 - Develop Thermal Treatment Unit Offgas CEM Monitors (PBS No. ID-WM-101)
- ID-S.1.02 & ID-2.1.18 - Continuous Emissions Monitors for Offgas Analysis (PBS No. ID-HLW-101)

TECHNOLOGY BENEFITS

This compact high-resolution spectrometer enables the field operation of the air-ICP-AES CEM and other optical-emission based CEMs. It achieves this by reducing the size of the optical system while providing superior resolution for reduced spectral interferences and for the ability to measure the isotopic composition of actinide materials in the sample stream. It allows deployment in areas where the size of conventional spectrometer instrumentation is a problem. It provides more rapid, user-programmable spectral switching than spectrometers of comparable resolution, and better resolution than spectrometers of comparable size. The advantages of this technology are that it makes the implementation of CEM technologies based on spectral emission more practical as alternatives to the conventional technology, and that it provides spectral resolution that makes the on-line monitoring of actinide isotopes practical. Successful deployment of the air-ICP-AES and the AOTF-echelle spectrometer system for the continuous monitoring of metals will minimize or eliminate the need for the labor and cost-intensive reference method, EPA Method 29, eliminate the need for extensive trial burns and feed stream characterization for the incinerator, and provide continuous data on metal concentration releases from the incinerator. By enabling CEM technologies for toxic metals and actinides, this technology assures compliance with release limits, thereby minimizing risk to public health and maximizing public confidence.

TECHNOLOGY CAPABILITIES/LIMITATIONS

Combined with the air-ICP-AES, this spectrometer can continuously monitor several metals in an offgas stream. The system is completely solid-state and computer controlled with no moving parts. An extensive software control package has been developed that allows for easy spectral acquisition, calibration or standard additions, and continuous unattended monitoring. This software makes operation and maintenance by a well-trained technician feasible.

The original sampling system for the air-ICP-AES required cycled sampling (15 seconds on/15 seconds off) because of the need to draw material from a reduced-pressure sample stream and inject it into the atmospheric pressure plasma of the ICP. This duty cycle may limit the number of elements that may be monitored during a single sample injection, depending on the integration time required for the desired detection limits. However, that limitation may be overcome by a number of measures. First, the emission source may be configured to operate at a reduced pressure, continuously drawing sample into the plasma. A reduced-pressure air-ICP-AES and sampling system was developed at Ames Laboratory and tested in FY 1999 at the Diagnostic Instrumentation and Analysis Laboratory (DIAL) at Mississippi State University. A dual-stage isokinetic sampling technique is used to continuously introduce sample gas into the reduced-pressure air-ICP-AES system for analysis. Second, an AOTF may be incorporated into the spectrometer that can select more than one spectral window at a time. As long as these features do not overlap on the linear array detector, the system could be used as a simultaneous detector for a number of elements. For example, for the field prototype spectrometer assembled during FY 1998, the emission spectra for selected lines of As, Be, Cd, Cr, Hg, Pb, U-235, and U-238 do not overlap on the detector and could be detected simultaneously using an AOTF capable of operating at two or more frequencies.

COLLABORATION/TECHNOLOGY TRANSFER

The air-ICP-AES system has been developed and operated at DIAL, Mississippi State University. The air-ICP-AES is simply one of many possible emission sources that can effectively make use of the size, cost, resolution, and speed advantages of this spectrometer. Discussions have begun with developers at Massachusetts Institute of Technology who are working on a CEM based on microwave-induced plasma. Work is being done in conjunction with personnel at the National Institute of Standards and Technology (NIST) to make use of ICP spectral data, accumulated by Ames Laboratory staff, to improve spectral line selection and interference checking in ICP-AES analyses. The spectrometer technology is not patented, but has been offered for licensing by Iowa State University.

Publications and Presentations

- D. P. Baldwin, D. S. Zamzow, D. E. Eckels, G. P. Miller, R. Wiser, and S. Tao. 1999. Testing of a Continuous Sampling Air-ICP System as a Continuous Emission Monitor at the Diagnostic Instrumentation and Analysis Laboratory, September 12-17, 1999. Ames Laboratory Report IS-5138.
- D. P. Baldwin, D. S. Zamzow, D. E. Eckels, and G. P. Miller. 1999. A continuous sampling air-ICP for metals emission monitoring. *SPIE Proceedings: Environmental Monitoring and Remediation Technologies II* 3853: 213-220.
- D. P. Baldwin, D. S. Zamzow, D. E. Eckels, and G. P. Miller. 1998. AOTF-echelle spectrometer for air-ICP-AES continuous emission monitoring of heavy metals and actinides. *SPIE Proceedings: : Environmental Monitoring and Remediation Technologies* 3534: 478-486.
- D. P. Baldwin, D. S. Zamzow, and G. P. Miller. March 30,1998. A high-resolution interferometric spectrometer for continuous emission monitoring. *Symposium on Analytical Applications of AOTF, at the American Chemical Society National Meeting in Dallas, TX.*
- D. P. Baldwin and D. S. Zamzow. 1997. Limits of detection for an AOTF-FFP spectrometer in ICP atomic emission spectroscopy. *Talanta* 45: 229-235.
- D. P. Baldwin, D. S. Zamzow, and A. P. D'Silva. 1996. High-resolution spectroscopy using an acousto-optic tunable filter and fiber-optic Fabry-Perot interferometer. *Appl. Spectrosc.* 50: 498-503.
- D. P. Baldwin, D. S. Zamzow, and A. P. D'Silva. 1995. Detection limits for hazardous and radioactive elements in airborne aerosols using inductively coupled, air plasma-atomic emission spectrometry. *J. Air & Waste Management Assoc.* 45: 789-791.

ACCOMPLISHMENTS AND ONGOING WORK

The Principal Investigator participated in a demonstration of a previous generation spectrometer in partnership with a demonstration of the DIAL air-ICP-AES at EPA in North Carolina in September 1997. A report detailing the results of that test and the performance of the system was prepared. Development of the next generation array-based echelle system in FY 1998 was in response to shortcomings of the previous system. The limitations included limited speed because of the scanning nature of a system using a single-element detector, and limited resolution and range because of the optical coatings on the interferometer. The new generation AOTF-echelle system delivered to DIAL addresses all of those problems and was demonstrated with the DIAL air-ICP-AES during FY 1998. The field prototype of this new system was completed and it showed significant improvement over the previous system in UV resolution (1 in 50,000) and wavelength coverage (200 - 425 nm). The improved wavelength range of the new detection system permits the analysis of the isotopic composition of actinide materials as well as the monitoring of toxic metals. During FY 1999, a reduced-pressure air-ICP-AES system was assembled to introduce sample continuously, instead of periodically drawing sample gases into a sample loop for injection into the plasma. This system was tested at DIAL; there was good agreement between the analytical results obtained using the air-ICP-AES echelle spectrometer system and those obtained using EPA Reference Method 29. During FY 2000, a multi-frequency AOTF is being incorporated and tested with the echelle spectrometer to improve the speed of the system to allow selection of 3 spectral windows for simultaneous monitoring of metals, rather than sequential AOTF-echelle analyses. A modified system is also being developed for monitoring Hg in offgases by atomic absorption using the echelle spectrometer and a mercury lamp to simultaneously measure signal and background absorption.

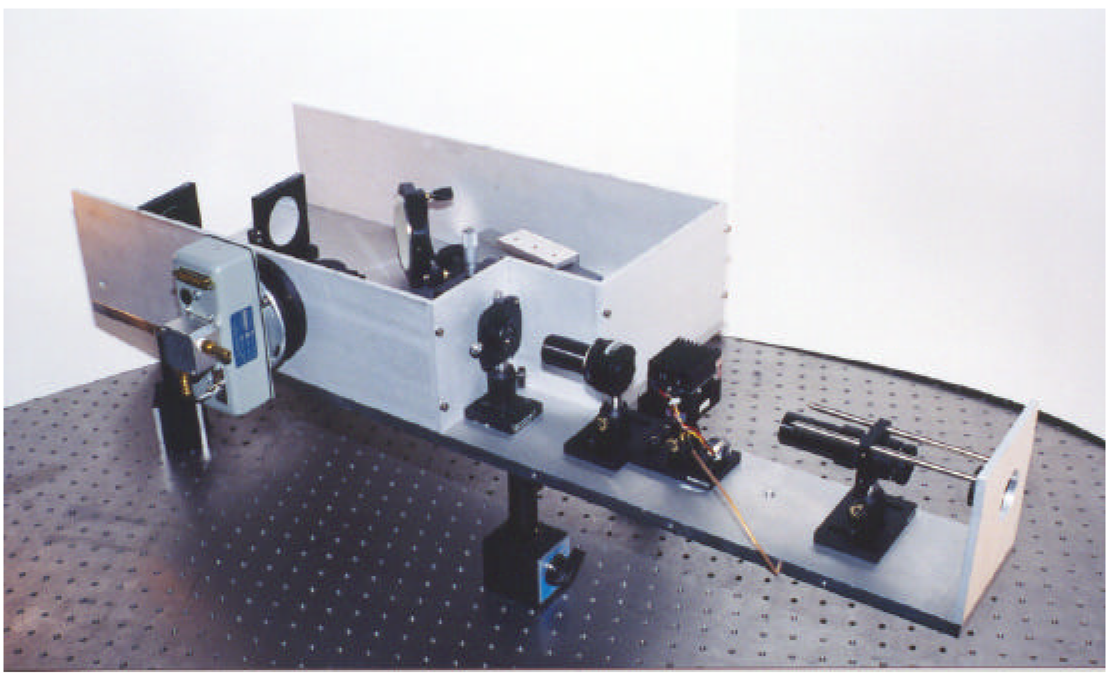
TECHNICAL TASK PLAN/ TECHNICAL MANAGEMENT SYTEM INFORMATION

TTP No./Title: CH17C233 - Development of a Multi-Element Metal Continuous Emission Monitor for Compliance Monitoring
Tech ID/Title: 1564 – Compact High Resolution Spectrometer

CONTACTS

David P. Baldwin
Principal Investigator
Ames Laboratory
Iowa State University
9 Spedding Hall
Ames, IA 50011
(515) 294-2069 fax: -4748
dbaldwin@ameslab.gov

Miles Dionisio
Technical Program Officer
U. S. Department of Energy
Chicago Operations Office
9800 S. Cass Avenue
Argonne, IL 60439
Phone: (630)252-2499 fax: -2654
miles_dionisio@ch.doe.gov



A high-resolution acousto-optic tunable filter (AOTF) echelle spectrometer is one of the instruments being tested to determine its capabilities for continuously monitoring toxic metals in DOE incinerators emissions to assure compliance with draft EPA regulations.